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Planetary Variations of Stratospheric Temperatures

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ABSTRACT—Radiances emitted from the atmosphere near 669.3 cm^{-1} in the center of the 15-μm CO_2 band were measured from the Nimbus 3 satellite. Changes in observed radiance correspond to weighted temperature changes of the upper 100 mb of air. The seasonal march of latitudinally averaged radiances is presented from 80°N to 80°S. The latitudinal and seasonal variations of radiance are removed from the data. The residuals emphasize the fact that winter polar stratospheric warmings are accompanied by stratospheric coolings in the Tropics and summer hemisphere. A warming of about 7°K near latitude 50° is accompanied by a cooling of about 1°K at the Equator. However, much larger warmings at latitudes near the poles do not produce correspondingly large coolings at the Equator.

The synoptic distributions of radiances on 2 days are discussed: (1) the day when the average latitudinal radiance was a minimum in polar latitudes and (2) the day when the polar warming reached its maximum. The wave number 1 pattern in middle and high latitudes of the Northern (winter) Hemisphere is evident. In the Southern (summer) Hemisphere, wave numbers 2 and 3 dominate. The large latitudinal difference of the radiances, on the day before the warming begins, reaches a value corresponding to about 15°K between 30° and 50°N at about 20°W longitude.

1. INTRODUCTION

In an earlier paper (Fritz and Soules 1970), we discussed some measurements from the Satellite Infrared Spectrometer (SIRS) on Nimbus 3; hereafter that paper will be referred to as F-S(70). In particular, we analyzed the data from one channel centered at 669.3 cm^{-1} in the 15-μm band of CO_2. The energy in this channel comes mainly from the stratosphere and indicates changes in weighted temperature of the upper 100 mb of atmosphere. The seasonal variations of outgoing radiance for the period from mid-April 1969 to mid-March 1970 were presented for latitudes from 80°N to 80°S. In addition, an analysis was made for the period April–October 1969; the latitudinal and seasonal variations were removed, and the residual variations were discussed as a function of time and latitude. The main result showed that, when a temperature rise occurred in the winter (or Southern Hemisphere) polar stratosphere, a temperature decrease occurred in the stratosphere of the Tropics and of the summer hemisphere, at least up to latitude 40°N.

In this paper, we extend the analysis of the data to the whole year with the seasonal and latitudinal variations removed and concentrate on the later period, October 1969–mid-April 1970. This period includes the Northern Hemisphere winter, during which a large-amplitude warming occurred in the polar stratosphere, with a corresponding decrease in temperature in the Tropics and summer or Southern Hemisphere.

The variations of the radiance, $\overline{R}_w$, emitted by the whole earth are discussed, both seasonally and for selected dates. The ratio of $\overline{R}_w$ for January to June is 1.03, although the solar energy absorbed by the stratosphere probably varies by 1.07. During episodes of polar stratospheric warmings, the average temperature change for the whole stratosphere is close to zero.

2. SEASONAL VARIATION OF RADIANCES

The seasonal variation of radiances is illustrated in figure 1. The time variation of the radiances at several latitudes is shown. The radiances are the average values around latitude circles observed each day when the satellite was northbound.[1] At each latitude, the data for a 4° latitude belt, centered on the latitude, were included. Thus, the data at each latitude contain about 100 observations each day, and the instrumental noise is highly suppressed. Figure 1 indicates a relatively smooth rise in radiance in both hemispheres from spring to summer in nontropical latitudes and a smooth decrease from summer to autumn. But in the winter of both hemispheres, large deviations from the smooth trend occurred. This was especially pronounced in the Northern Hemisphere; the amplitude of the stratospheric warming at 60°N and 80°N in December–January was much larger than that of the warmings which occurred in the Southern Hemisphere during July and August. Similarly, at the Equator and at 30°N and 30°S, deviations from the smooth trend were more pronounced during the Northern Hemisphere winter than they had been in the Southern Hemisphere winter.

3. NONSEASONAL VARIATIONS

To demonstrate these deviations more clearly, one must remove the seasonal variation from the data at each

[1] The southbound data show the same results as those presented in this paper. However, on those occasions when the satellite did not take observations during part of an orbit, southbound data were used to supplement the northbound data.

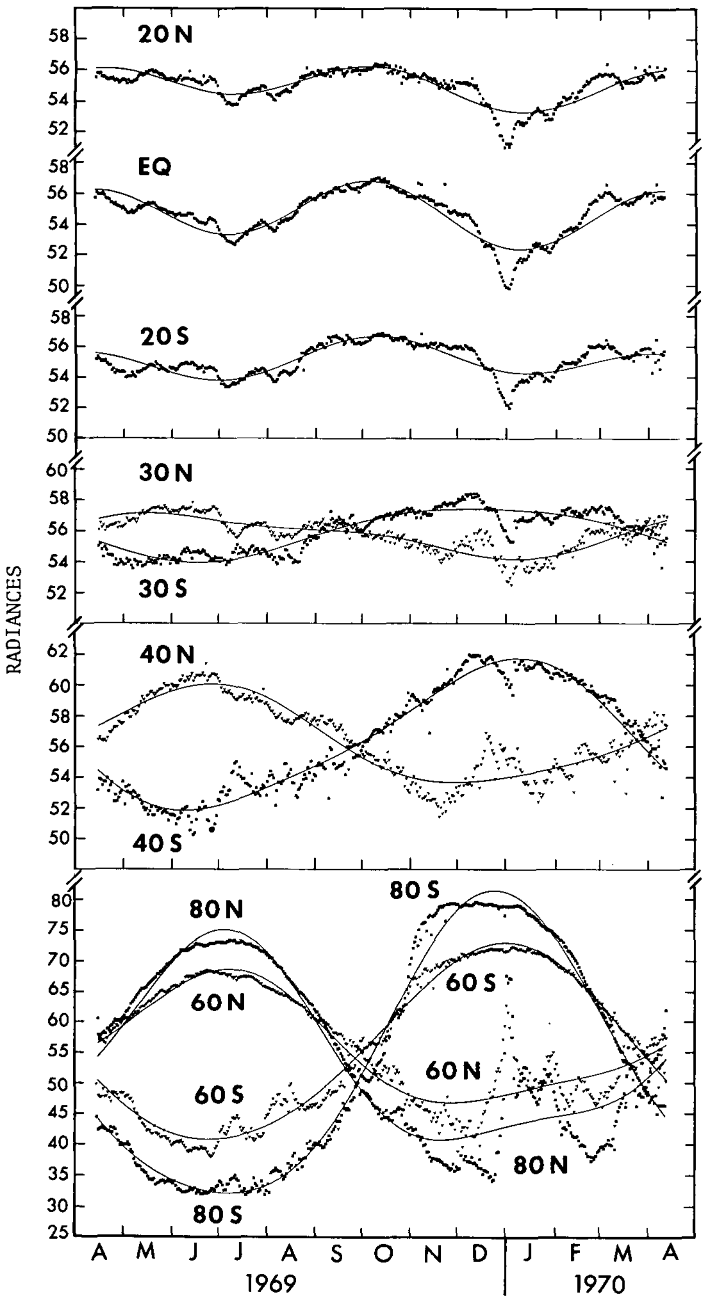

FIGURE 1.—Annual march of radiances at 669.3 cm⁻¹ for selected latitudes showing the seasonal warming and cooling of the stratosphere. Smooth curves are radiance values [$\mathrm{mW \cdot m^{-2} \cdot (ster)^{-1} \cdot (cm^{-1})^{-1}}$] calculated from the data by a finite Fourier-series method using annual and semiannual periods. Data at one latitude represent observations for a 4° latitude zone averaged daily around the latitude circle.

latitude. In our previous paper [F-S (70)], in which we analyzed the data for April to October, the seasonal variation was removed by fitting curves to the data by the least-squares method. This could be done quite satisfactorily because during April–October 1969 only small amplitude changes occurred. The resulting curves fitted the data well at all latitudes, especially in the summer northern polar latitudes. [See fig. 2 in F-S (70).] For the present study, a finite Fourier-series analysis was used instead of the least-squares method. The results of both analyses are equivalent. Problems arise in using the harmonic analysis to fit all the data for 1 yr. At latitude 80°N, for example, the large-amplitude change that occurred between December 1969 and January 1970 strongly influences the Fourier-series approximation, so that a poor fit is obtained even in the summer months at northern polar latitudes. What is really desired is a standard reference for the radiance distribution at each latitude for the whole year. This might eventually become available, perhaps as a mean of 30 yr of data; but since only 1 yr of data has been assembled for analysis so far, the finite Fourier-series curves have been selected to serve as a substitute for the latitude-time standard reference. Two harmonics, having an annual and a semiannual period, have been fitted to the data.

The finite Fourier-series computations are shown in figure 1 by continuous curves superposed on the data curves. The residuals from these curves are shown in figure 2. Here, again, we see the out-of-phase relationship in the period April–September 1969, essentially as discussed previously in F-S(70); that is, when warmings (radiance rises) occurred in the winter Southern Hemisphere, coolings occurred throughout the Tropics and northward to about 40°N in the Northern Hemisphere summer. The radiance changes from the end of June to the middle of July are a good example of this. F-S(70) attributes the stratospheric cooling in the Tropics and summer hemisphere to large-scale upward motions in the stratosphere. However, the harmonic analysis fit for April–October 1969 was better in F-S(70), and details are probably better displayed in that paper and will not be discussed further here. For the period October 1969–April 1970, similar out-of-phase radiance relationships occur with, however, larger amplitudes in the northern winter. These large radiance changes indicate that somewhere in the stratosphere there was a similar type of out-of-phase temperature relationship.

The most notable phenomenon in figure 2 is the very large warming that occurred in the northern winter and reached its peak on about Jan. 1, 1970, from 50°N to 80°N. At nearly the same time, perhaps a day or two later at some latitudes, the minimum radiance was observed from 30°N southward to at least 50°S. Smaller out-of-phase maximum–minimum radiance changes can also be noted in figure 2; an example is notable on about March 1, when a minimum was observed north of 40°N and a maximum occurred from about 20°N to 30°S.

The tendency for the stratospheric Tropics to cool during stratospheric polar warming episodes has already been noted by Reed (1963) and by Julian and Labitzke (1965). Reed analyzed the "sudden warming" at 50 mb during early 1956 from 35° to 80°N. He surmised from considerations of mass continuity that upward motions exist in the Tropics during the polar warming interval. At 50 mb, he found that the temperature at 50°N was the same at the beginning and the end of the period. At 35°N, the temperature had decreased about 5°K; while at 80°N, the temperature had increased about 50°K.

Julian and Labitzke show latitude profiles of zonally averaged 30-mb temperatures from 10° to 80°N for the stratospheric warming episode in 1963. In their case, the latitude at which the temperature was the same before

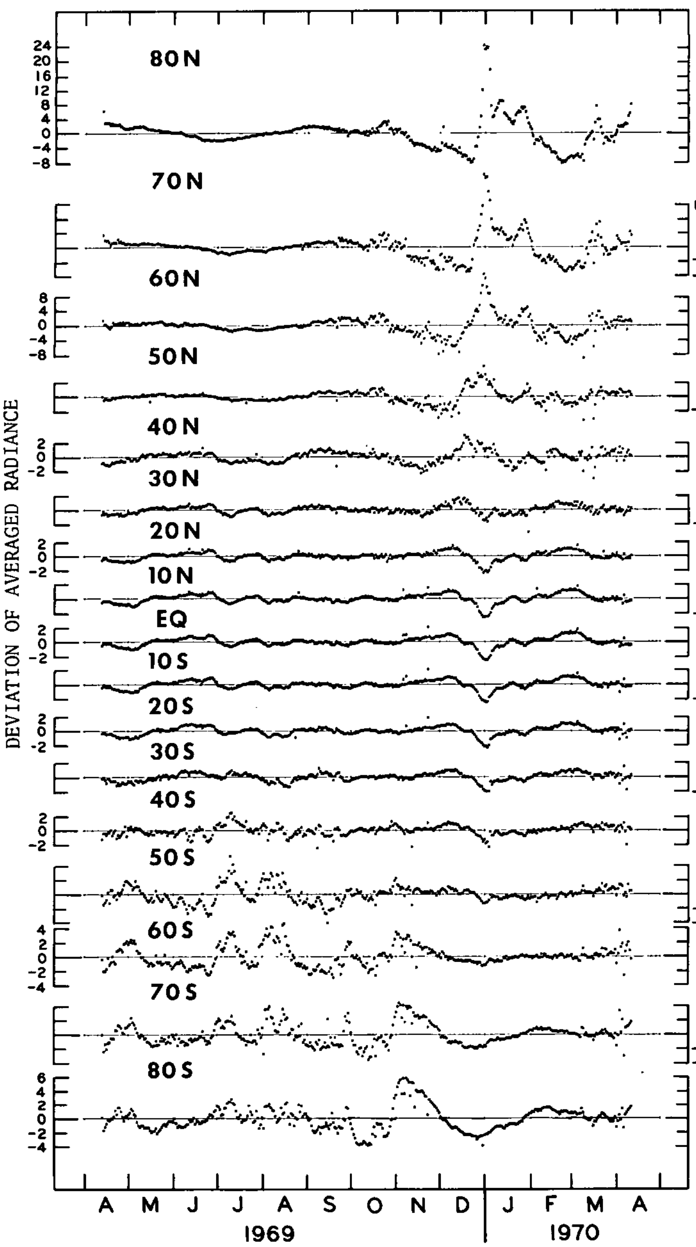

FIGURE 2.—Deviation of averaged latitudinal radiance [$mW \cdot m^{-2} \cdot (ster)^{-1} \cdot (cm^{-1})^{-1}$] from a finite Fourier-series fit for 80°N–80°S from Apr. 14, 1969, to Apr. 13, 1970.

the warming began and at the end of the warming period was about 43°N. At 10°N, the temperature decreased by about 6°K, while at 80°N, the temperature increased by about 50°K. Neither Reed nor Julian and Labitzke extended their data across the Equator and into the Southern Hemisphere.

In each of the SIRS events described above, the maximum and minimum were observed on nearly the same dates. There are, however, some events that seem to have moved northward with time. Noteworthy among these is the minimum that preceded the major maximum of Jan. 1, 1970. This minimum seems to have occurred at latitude 30° and 40°N in mid-November and to have progressed northward, reaching 80°N after the middle of December. A minimum may also be detected as early as November 1 from 10°N to 30°S, if one accepts the rather small change of slope in figure 2 as an indication. This may be associated with the maximum radiance seen in figure 2 on about November 1 for 40°–80°S.

The maxima of figure 2 in the southern polar latitudes at the beginning of November are a result of the differences between the Fourier-series fit and the measured data, as shown in figure 1. Nevertheless, they seem to be real maxima, caused by dynamic influences. If solar heating were the main control, one would expect a continued radiance rise in figure 1 after December 1, with a maximum near January 1 and greater symmetry about that date; that is, the symmetry for 80°S in that case would be similar to the curve for 80°N about July 1. Moreover, on November 1 at 40°S (fig. 1), there was an unambiguous maximum in the radiance; the sharp change in slope at 60°S on that date also attests to the reality of the dynamic maximum at 80°S. Thus, the distortion of the 80°S curve suggests a warming by dynamic factors in November. As mentioned above, a weak minimum may also have existed on about November 1 near the Equator. Thus, the polar maximum may have been connected with a dynamically produced minimum in the Tropics on about November 1, a minimum that may have progressed to 80°N in mid-December.

Note also in figure 2 the maximum that occurred from 20°N to 40°S in mid-December, at the same time that the minima occurred at 50° and 60°N. The simultaneous occurrence of these two events suggests that the large-scale dynamic process, which connected the northern polar warming and the associated cooling in the Tropics, began on about December 10.

All of this, connecting events at both poles, may perhaps be tied together with the following reasoning. It had already been shown in F-S(70) that coolings in the winter polar regions are accompanied by warmings in the Tropics; this is evident in figures 1 and 2 of this paper. The relative cooling in November (fig. 2) in the Southern Hemisphere polar region suggests the possibility of a rising motion and/or heat transport out of that region by eddy or meridional fluxes. This polar cooling was accompanied by a small rise in radiance in the latitude zone from 30°S to 20°N, suggesting the initiation of a systematic small sinking motion (or reduced upward motion) in the Tropics on about November 1 and the creation of a warmer than normal body of air in the tropical stratosphere. However, we note that the radiance was also decreasing throughout November from 80° to 50°N. Therefore, although the initiation of the warming at the Equator is more nearly coincident in time with the beginning of the Southern Hemisphere polar cooling, the cooling in the high northern latitudes may also have been connected with the tropical warming.

The change from cooling to warming began later, in mid-November, at 30° and 40°N. This suggests that either the warm pool of air that had already been formed in the Tropics moved northward or that an area of sinking air expanded both northward and southward; at 40°S, the radiance also began to rise near the end of November. Throughout November, however, the radiance at 50°N continued to decrease (fig. 2). This produced an enhancement of the north–south temperature gradient between 40° and 50°N. This large gradient, suggesting a large increase of wind speed with height through the thermal wind relation, may be a condition that precedes major warmings, as was also found in F-S(70) for a Southern Hemisphere polar warming. Then, on about December 10, with all conditions apparently satisfied for the beginning of the major warming in the high northern latitudes, the warming begins at 50° and 60°N. At the same time, the radiances in the Tropics, which had been rising, begin to fall. This suggests that the vertical motion in the Tropics now has changed from a sinking or reduced upward motion (associated with the southern polar cooling) to a rising motion associated with the pronounced warming in north polar latitudes. Later in December, the warming began at 70° and 80°N. That warming, probably due to both eddy advection and localized sinking motion, reached its climax from 50° to 80°N on about January 1; this is also the date when the minimum radiance from 20°N to 60°S was reached (fig. 2).

If the "explanation" of the sequence of events just described is valid, then it implies that the dynamic event near the South Pole and the events near the North Pole, in November, were associated with the establishment of warm air in the northern Tropics. This led to an enhanced temperature gradient near latitude 40°N. The thermal wind then suggests a strong wind at high altitudes in the stratosphere, a possibly necessary (Matsuno 1971), but not sufficient, condition for the initiation of the large stratospheric warming episode. In this way, the south polar warming and cooling in November may have been a contributing factor to the subsequent warming near the North Pole in December 1969–January 1970. It will be interesting to see whether a similar event occurred during the Northern Hemisphere stratospheric warming of December 1970–January 1971.

After January 1, the north polar radiances decreased while the tropical and summer hemisphere radiances increased. This may have been a result of a reversal in direction of the vertical motion and/or eddy and meridional advections. Alternatively, it may also have been caused by relaxation or cessation of dynamic factors; in that case, radiative cooling at the high northern latitudes and solar radiative warming in the Tropics and summer hemisphere could act to restore the stratospheric temperatures closer to the radiative equilibrium values, which had been upset by the earlier dynamic events.

To emphasize the out-of-phase relation shown in figure 2, we plotted in figure 3 the deviations of the average radiances from the Fourier-series value for selected dates. The dates of major maxima and minima in figure 2 were chosen. The upper part of figure 3, essentially the same as figure 4 in F-S(70), shows that the poorer Fourier-series fit in figure 1 of this paper, for the April–October 1969 period, did not influence the main result significantly. The lower part of figure 3 includes dates after October 1969. This also demonstrates the out-of-phase relation; at a point somewhere between latitudes 20° and 40°N, essentially no difference from the Fourier-series fit occurred for these particular dates. For January 27 (curve

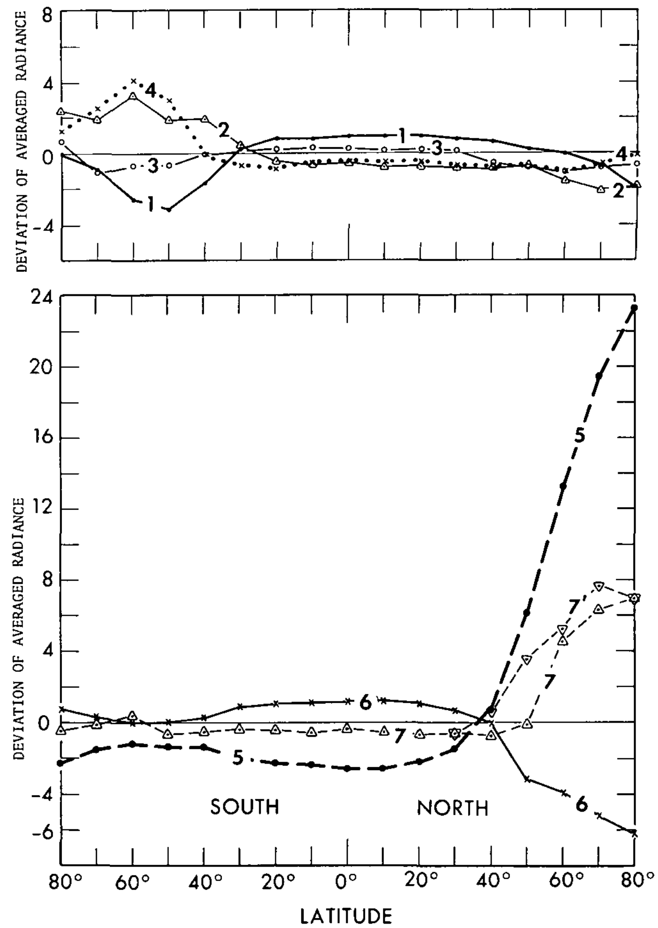

FIGURE 3.—Latitudinal distribution of the deviation of averaged radiances [mW·m^{-2}·(ster)$^{-1}$·(cm^{-1})$^{-1}$] from finite Fourier-series value for selected dates when major maxima and minima occurred (1) June 26, 1969, (2) July 10, 1969, (3) July 26, 1969, (4) Aug. 8, 1969, (5) Jan. 2, 1970, (6) Mar. 1, 1970, (7) Jan. 27, 1970, and (7′) Jan. 29, 1970, at 70° and 80°N, Jan. 31, 1970, at 50° and 60°N, and Feb. 1, 1970, at 40°N.

7, fig. 3), the curve crosses the zero radiance axis near latitude 50°N. However, in this case, the maxima in figure 2 occurred progressively later, by a day or so, as the latitude decreased from 80° to 40°N. If the maximum radiance at each latitude near January 27 is plotted, then the zero or nodal point occurs near 35°N. This is illustrated in figure 3 by curve 7′. Figure 2 also shows that the smallest changes with time occurred near latitude 30°N near that date. Therefore, the zone of transition or "nodal" zone is generally between 20° and 40°N. Nevertheless, we note from figure 2 that, even at the latitude that seems to act as a nodal point in figure 3, small variations often occurred but not precisely on the same dates as those in figure 3.

Since the out-of-phase relationship has been clearly demonstrated, it may be useful to express the relationship quantitatively. This has been done in figure 4 where the *differences* in radiances between some successive maxima and minima at selected latitudes have been plotted from the data of figure 2. For example, the point labeled "5" represents the radiance increase (in fig. 2) at 80°N from the minimum on Dec. 23, 1969, to the maximum on Jan. 2, 1970, and also the decrease in radiance at the Equator between the same dates.

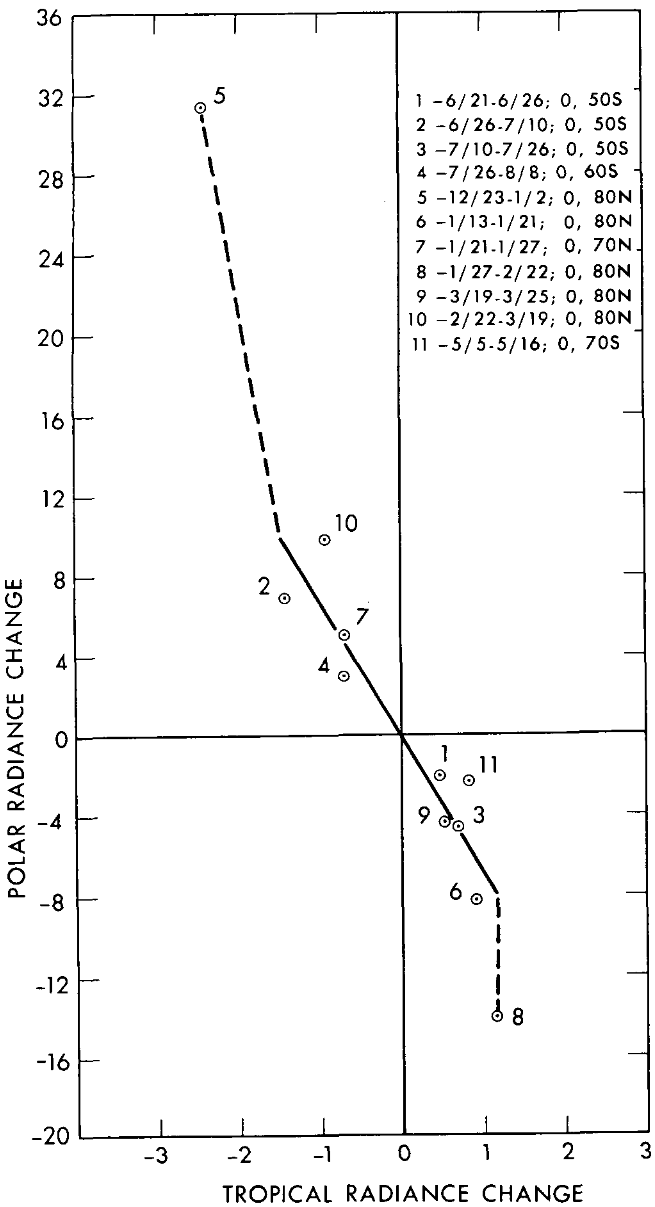

FIGURE 4.—Relationship between polar (high latitudes) radiance change [mW·m^{-2}·(ster)$^{-1}$·(cm^{-1})$^{-1}$] and tropical (low latitudes) radiance change for selected periods when major warming and cooling trends occurred.

In figure 4, when the radiance [2] in the polar regions decreases by about 7 mW/, corresponding to about 7°K temperature decrease averaged over a deep region of the stratosphere, the Tropics warmed by about 1°K averaged in a similar way. When the polar regions warm by 7 mW/, the Tropics cool by about 1 mW/. Up to this range of values, the relationship shown in figure 3 seems to be nearly linear. But when the polar regions near 80° latitude underwent much larger changes, the corresponding changes in the Tropics were relatively small. Thus, the nonlinear effect in figure 4 is produced by the very large temperature changes that predominated at very high latitudes, where the area of the earth per latitude zone is small.

Perhaps this suggests that the total internal energy change of the whole stratosphere is small or zero during a polar warming episode. (This is discussed later.) Then, if a given temperature decrease occurs in the Tropics and summer hemisphere, it will be compensated for by a warming in the winter polar hemisphere. If the polar warming predominates at high latitudes, say at latitude 80° where the mass of air is small, then a large temperature increase must occur as a compensation. If the temperature change predominates at subpolar latitudes, say at latitude 50° where the circumference of the latitude circle is larger, then the temperature increase need not be quite as large because more mass is available for heating. If the values in figure 4 are multiplied by cosine of the latitude to account for the smaller mass near the poles, the data fall more nearly on a straight line.

4. SYNOPTIC VARIATIONS

Figures 1–4 refer only to the radiance averages around latitude zones, but the events portrayed are by no means uniform around the latitude zones. This is illustrated in figures 5–7. Figure 5 is a Mercator chart for Dec. 3, 1969, when the radiances at latitude 60°N were near a minimum after the seasonal trend was removed. In figure 5, the Fourier-series radiances have been removed at each latitude, so that the isolines represent deviations from the Fourier-series value; the Fourier-series radiances for each 10° of latitude for December 3 are shown along the right margin. A similar Mercator chart is also shown for Jan. 2, 1970 (fig. 6), at the time of the maximum polar warming.[3] Finally, in figure 7, the radiance differences (fig. 6 minus fig. 5) are shown.

A noteworthy feature in figure 5 is the wave number 1 pattern in high northern latitudes. The radiances are 10 mW/ below the latitudinal Fourier-series "mean" south of Greenland and over 12 mW/ above the latitudinal mean north of Alaska–Eastern Siberia. Perhaps of even greater significance is the large south–north gradient at about 40°N, south of Iceland. This gradient is produced by the low radiance south of Greenland and the relatively high radiance at 30°N over the Middle East. The Fourier-series fit radiance difference between 30° and 50°N is 3.9 mW/; superposed on this is a difference of about 11 mW/ as indicated by the isolines in figure 5. The gradient is represented, therefore, by a difference of about 15 mW/, or about 15°K, for a deep layer of the stratosphere between 30° and 50°N. This implies a strong vertical wind shear and strong wind at high levels of the stratosphere—a condition that may be associated with stratospheric warming in polar regions (Matsuno 1971). A difference of 14 mW/ was observed between 30° and 50°S prior to the Southern Hemisphere warming event which began on June 25, 1969 [F-S(70)].

Note the shorter wavelength pattern in the Southern Hemisphere summer. Wave number 3 seems to dominate; of course, the amplitude is much smaller than it is in the winter hemisphere. The Southern Hemisphere summer seems to have a better defined pattern than the Northern

[2] The radiance unit, mW·m^{-2}·(ster)$^{-1}$·(cm^{-1})$^{-1}$, has been shortened to mW/.

[3] The radiance variations in figures 5 and 6 resemble the temperature variations in the 10- to 30-mb layer.

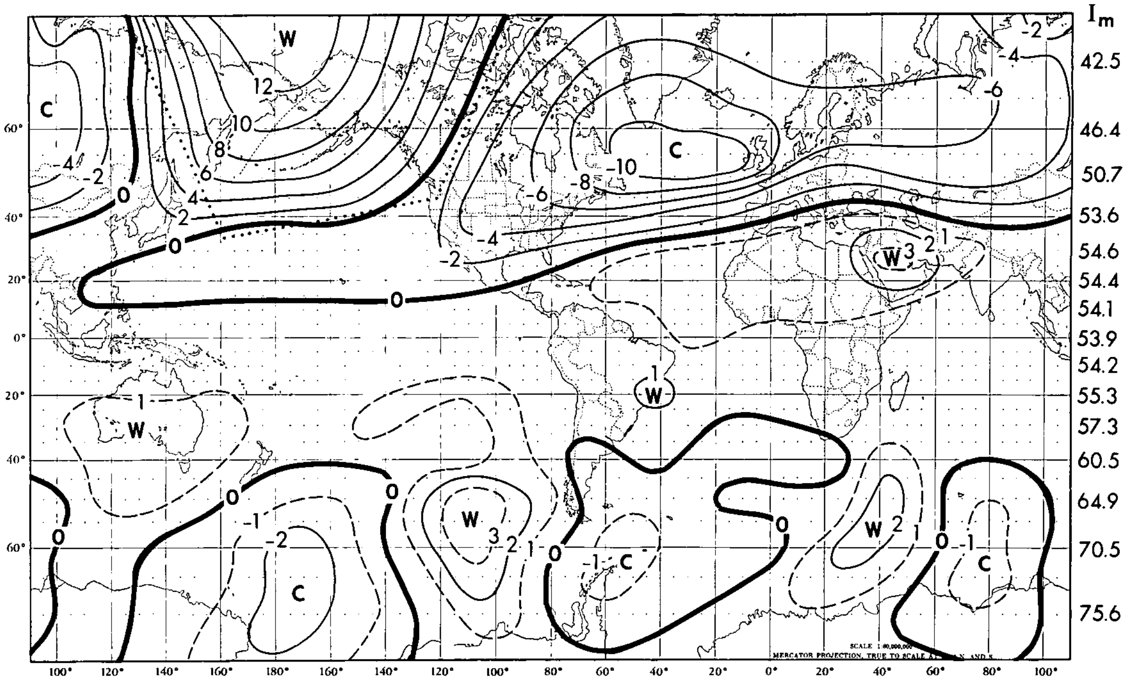

FIGURE 5.—Map for Dec. 3, 1969, of radiance deviation [mW·m^{-2}·(ster)$^{-1}$·(cm^{-1})$^{-1}$] from I_m, the finite Fourier-series value for a given latitude, shows warm (W) and cool (C) areas. Data-sparse region caused by spacecraft telemetry schedule is enclosed by dotted lines in the Alaska area.

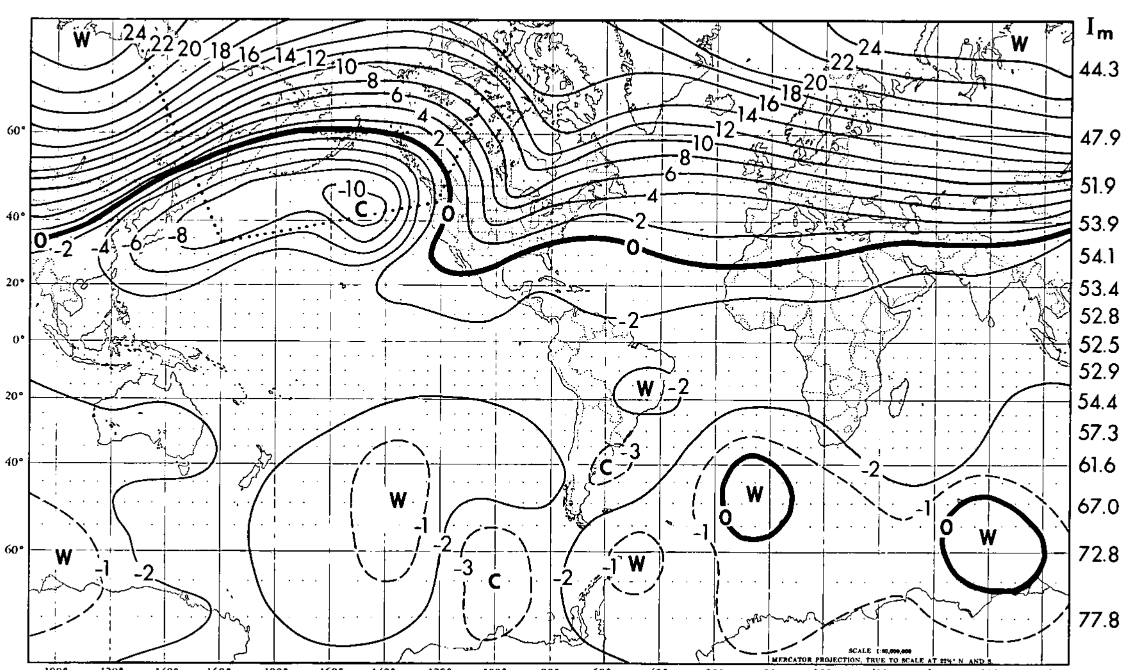

FIGURE 6.—Same as figure 5 for Jan. 2, 1970.

Hemisphere summer had during a corresponding time (June 25, 1969) in the polar warming cycle. [See fig. 5 in F-S(70).]

Figure 6 shows that the highest radiances appeared north of Siberia. At the same time, colder air was present south of Alaska and the Aleutian Islands. This juxtaposition of cold air to the south and warm air to the north should produce a marked decrease of west wind with height, overcoming the normal tendency suggested by the Fourier-series values in the margin of figure 6.

Finally, figure 7 shows that a warming had produced an increase of over 28 mW/ over northern Siberia, but a cooling of 14 mW/ occurred near the Aleutians. At the same time, in agreement with figure 2, the Tropics from 20°N to almost 40°S experienced a cooling of about 2–3 mW/ everywhere with an extreme of about 5 mW/ over

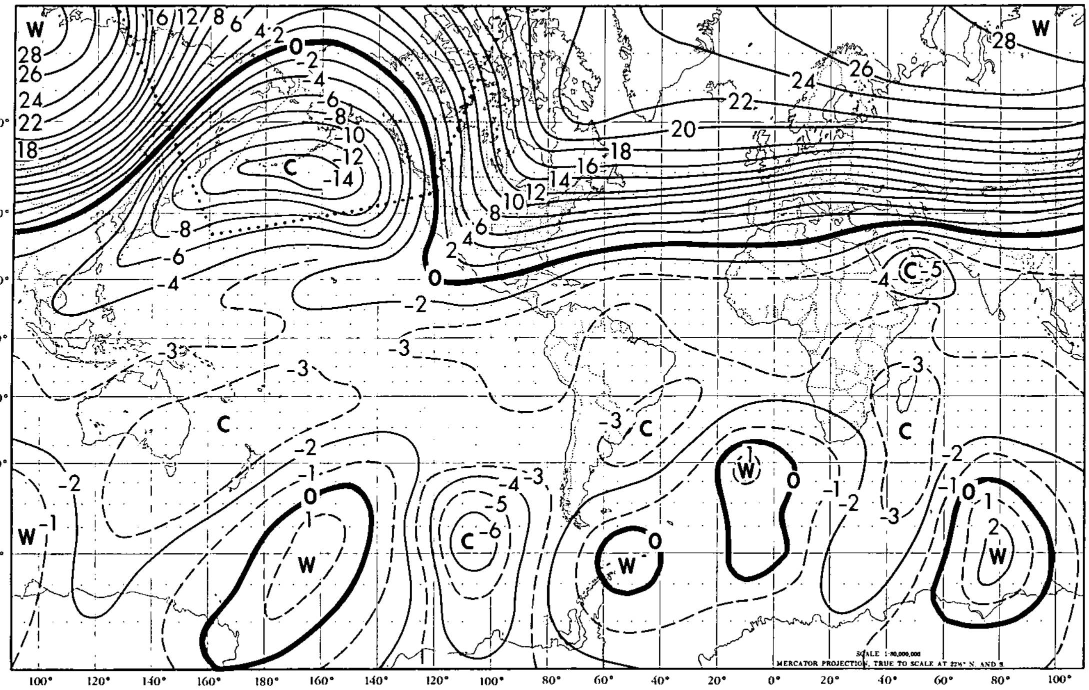

FIGURE 7.—Change in radiances [mW·m^{-2}·(ster)$^{-1}$·(cm^{-1})$^{-1}$] from Dec. 3, 1969 (fig. 5), to Jan. 2, 1970 (fig. 6).

Saudi Arabia, where the warm air had contributed to the strong gradient in figure 5, just before the warming began. The Tropics had also cooled everywhere during a Southern Hemisphere warming in June–July 1969, but the tropical cooling then was about 1–2 mW/ [F-S(70)].

5. OUTGOING RADIATION OF THE WHOLE STRATOSPHERE

It is not uncommon to read about "sudden stratospheric warmings." But what is actually meant is "sudden *polar* stratospheric warmings." For the stratosphere as a whole may not warm at all during these familiar events; as shown in figures 3 and 4, for example, the Tropics and summer hemisphere cool in the stratosphere when the winter polar regions warm.

To estimate what happens to the stratosphere as a whole, we computed the average outgoing radiance for the whole world, $\overline{R}_w$, in the 669.3 cm^{-1} band. This is given by

$$\overline{R}_w=\frac{R_w}{4\pi a^2}=1/2\int_{-\pi/2}^{\pi/2} R_\phi \cos\phi d\phi \tag{1}$$

where R_w is the total outgoing radiation for the whole world, a is the radius of the earth, R_ϕ is the average radiance around a latitude circle, and ϕ is the latitude. In the computation, R_ϕ was available for every 10° of latitude from 80°S to 80°N, and $\Delta\phi$ was taken as 10°. Therefore, eq (1) was approximated by

$$\overline{R}_w=\frac{\pi}{36}\sum_{1}^{17} R_{\phi n} \cos\phi_n+P. \tag{2}$$

In eq (2), 10° was set equal to $\pi/18$ radians, and P accounts for the radiance in the latitude zones from 85° to 90° at

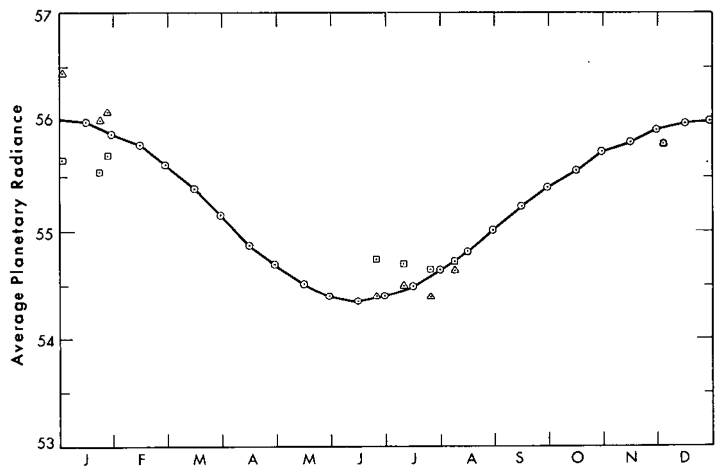

FIGURE 8.—Annual variation in planetary radiance [mW·m^{-2}·(ster)$^{-1}$·(cm^{-1})$^{-1}$] at 669.3 cm^{-1} from Apr. 14, 1969, to Apr. 13, 1970, calculated from data by a finite Fourier-series method for a 12-mo period (circles), and for some selected dates using observed data from northbound (triangles) and southbound (squares) orbits.

both poles, which was not measured. Because cos ϕ is small there ($P\approx 0.2$ mW/), it was not added to the computation shown in figure 8. However, since P varies little with season, the shape of the curve in figure 8 will remain essentially unchanged.

This computation was made not only for some anomalous days but also for the average monthly values of R_ϕ as given by the Fourier-series fit curves of figure 1. The results are shown in figure 8.

Figure 8 shows that, for the earth as a whole, there is a minimum radiance in June [4] and a maximum in January.

[4] If one uses the least-squares curves from F-S(70), the minimum appears in July.

This might have been anticipated because the sun is closer to the earth in January than in June. However, the ratio of the $\overline{R}_w$ in December to $\overline{R}_w$ in June is 1.03. Because of the solar distance variation, the corresponding ratio of solar energy incident on the earth is about 1.07; presumably about 7 percent more solar energy is absorbed by the stratosphere in December than in June. Somehow, the difference between the absorbed and emitted energy must be taken care of by circulation factors or other radiative exchanges.

The values of $\overline{R}_w$ for the whole earth on the days when some of the maxima and minima occurred in figure 2 are also illustrated in figure 8. There does not seem to be any definite pattern for the anomalous days shown in figure 8. On Jan. 1, 1970, when the polar region reached its maximum radiance, the earth as a whole seemed to radiate more than the average, as shown by the northbound measurements. However, the southbound measurements show $\overline{R}_w$ below the curve on that day. It should be noted that more southbound orbits were missing, and the average is, therefore, probably less representative. However, on other days, the deviation from the mean curve of figure 8 was small; and on some of those days, the average values lay above the curve when the Tropics was cold, and on others they lay below the curve when the Tropics was warm. Therefore, the earth's stratosphere seems to radiate nearly the same amount near any one date, whether or not a polar warming or cooling was occurring. The large polar warming of Jan. 1, 1970, may have been an exception in which the warming overbalanced the tropical cooling; even if this was so, the net change was small.

Over 2,000 observations were used to compute one value of $\overline{R}_w$ in figure 8 on a particular day (triangle or square). Since the root-mean-square error of a single observation is about 0.25 mW/, the *instrumental* error is small, being less than 0.01 mW/. However, the sampling error may be larger. Therefore, the changes in figure 8 between dates that are close together may not be statistically significant and may have been caused by sampling errors.

6. CONCLUSIONS

From our analyses of the outgoing radiation in the most opaque part of the CO_2 band, much can be learned about the worldwide variations of stratospheric temperature. Figure 4 shows that the average latitudinal temperature change in the polar stratosphere is of opposite sign and about seven times larger than the simultaneous change in the tropical and summer stratosphere. However, temperature changes closer to the pole may be larger relative to the tropical changes.

On the basis of the 1-yr sample, 1969–70, the amplitude of the temperature changes in the polar stratosphere warming in the Northern Hemisphere winter was very much larger than warmings in the Southern Hemisphere. It is interesting to note the pronounced wave number 3 radiance distribution in the Southern Hemisphere summer (fig. 5); this did not seem to be the case in a corresponding situation in the northern summer [June 25, 1969, in F-S (70)].

The gradient of radiance in a small longitudinal zone centered near latitude 40°N was about the same just before the onset of the polar stratospheric warming in the Southern Hemisphere [F-S (70), fig. 5] and in the Northern Hemisphere (fig. 5, this paper). Will this gradient be representative of future polar warming episodes?

Finally, the outgoing radiation at 669.3 cm^{-1} for the whole world varies by about 3 percent from June to January. Since the stratosphere doubtlessly absorbs about 7 percent less radiation in June than in January, the difference between incoming and outgoing radiation must be explained either by heat transport out of the stratosphere or by some radiative exchange. The radiative exchange could be between the stratosphere and the cold tropopause region, especially in the Tropics. It is conceivable, but not likely, that seasonal changes in water vapor and ozone, or even carbon dioxide, could change the radiative properties of the stratosphere to account for the deficit in the radiation (at 669.3 cm^{-1}) in January relative to June.

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